77 Calibrations

Constrained Clade	Min Age	Max Age	Basis for Max Age	Oldest Fossil	PB	Comments/References for Oldest Fossil	Comments/References for Maximum Age
1. Monotremata	25	121	PB/PU	*Obdurodon*	*Teinolophos*	Woodburne et al. (1993)	Allows for the possibility that *Teinolophos* is a crown monotreme (Rowe et al. 2008), although Phillips et al. (2009) recovered this taxon as a stem monotreme.
2. Caenolestidae	0	15.97	PB		*Stilotherium* (2nd outgroup)		Goin et al. 2007, 2009
3. Didelphidae	11.608	28.1	SB	*Micoureus laventicus*		*Micoureus laventicus* (Goin 1997; Marshall 1976) is the oldest representative of Monodelphini; the oldest Didelphini is *Hyperdidelphis* (Reig et al. 1987).	Maximum age based on stratigraphic bounding [i.e., *M. laventicus occurs* in middle Miocene; base of early Miocene (1st stratigraphic unit) is 23.04 Ma and age of Chattian (2nd stratigraphic unit) is 28.1 Ma].
4. Didelphimorphia	11.608	66.0	PB	*Micoureus laventicus*	*Peradectes* (Puercan); *Minoperadectes* (Early Wasatchian)		Horovitz et al. (2009) recovered *Peradectes* (Puercan, minimum = 65.18) as a stem didelphimorph, which establishes a maximum of 66.0 Ma for the base of Didelphimorphia.
5. Peramelidae	4.36	23.8	PB	cf. *Peroryctes*	*Yarala kida*	Turnbull et al. (2003) report cf. *Peroryctes* from the Hamilton Local Fauna (minimum age = 4.36 Mya)	Schwartz 2006; Megirian et al. 2004; Woodburne et al. 1993. The Kangaroo Well Local Fauna from the latest Oligocene is approximately coeval with the Kutjamarpu Local Fauna. Woodburne et al. (1993) suggest an earliest age of ~23.8 Mya. *Yarala* is known from the Kangaroo Well Local Fauna.
6. Peramelemorphia	4.36	54.65	PB	cf. *Peroryctes*	Murgon "Stem perameloid" (2nd outgroup)	Turnbull et al. (2003)	Isolated teeth from Murgon (54.65 Ma) have suggested the possibility of peramelemorphians at this time (Godthelp et al. 1992; also see Meredith et al. 2008a). The maximum is based on phylogenetic bracketing and allows for the possibility that the putative peramelemorphians from Murgon belong to the second outgroup to the crown clade.

7. Dasyuromorphia	15.97	54.65	PB	*Barinya wangala*	Murgon "Stem perameloid"	*Barinya* is the oldest dasyurid and is known from Neville's Garden (Riversleigh) (Wroe 1999). This minimum assumes that thylacinids are the sister group to dasyurids + myrmecobiids following Miller et al.'s (2009) analysis of mt genomes. The oldest numbat fossils are from Pleistocene (`0.1 Ma) cave deposits (Long et al. 2002). The age of Neville's Garden is Faunal Zone B (~early Miocene according to Travouillon et al. [2006]). The upper limit of the early Miocene is 15.97 Ma.	Wroe 2003; Thylacinidae (1st outgroup)
8. Phalangeridae to Burramyidae	25	54.65	SB	*Eocuscus sarastamppi*		Case et al. 2009 (or 2010?); Etadunna Fm, Zone	
9. Petauridae to Pseudocheiridae	25.5	54.65	SB	*Paljara*		Woodburne et al. 1993	
10. Macropodoidea (=Macropodidae + Potoroidae)	24.7	54.65	SB	*Bulungamaya*		Kear et al. 2007; Kear and Pledge 2008; Woodburne et al. 1993	
11. Vombatiformes	25.5	54.65	SB	*Perikoala*		Woodburne et al. 1993	
12. Australidelphia + Didelphimorphia	65.18	83.8	SB	*Peradectes* (Puercan); *Minoperadectes* (Early Wasatchian)		Horovitz et al. 2009 reported Puercan *Peradectes* (age = 65.18 Ma) as the oldest crown metatherian. Benton et al. (2015) did not provide any rationale for excluding this taxon from crown Metatheria even though they cite Horovitz (2009) in support of a younger age for crown Metatheria.	
13. Vermilingua	15.97	56.0	PB	*Protamandua*	*Riostegotherium*		First outgroup is Tardigrada (Gaudin and Branham 1998). Second outgroup is Cingulata,

(=*Cyclopes* to *Myrmecophaga*)							which includes *Riostegotherium* from the Itaboraian. The Itaboraian was previously considered equivalent to the Selandian (Benton & Donoghue 2007), but Woodburne et al. (2014) suggest an early Eocene age (56.0 Ma maximum)
14. Tardigrada (=*Bradypus* to *Choloepus*)	15.97	41.3	PB	Megalonychidae	Late Eocene ungual (Carlini et al. 1990, 1992) from Antarctica may belong to Pilosa		1st outgroup is *Pseudoglyptodon* (max = base of Oligocene); 2nd outgroup is Vermilingua. Of these, the oldest fossil is *Pseudoglyptodon chilensis* (McKenna et al. 2006) from the early Oligocene (minimum age of *P. chilensis* = 31.5 Ma based on radiometric dating; McKenna et al. 2006). Phylogenetic uncertainty allows for the possibility that the Antarctic ungual (Carlini et al. 1990), which is from the late Eocene (~Bartonian) mammal locality of Woodburne and Zinsmeister [1984), is a stem sloth or stem anteater (see La Meseta chronology in Marenssi et al. 1994), and provides a maximum age of 41.3 Ma (base of Bartonian). Rose et al. (2005) refer to the "Antarctic supposed xenarthrans" as controversial forms.
15. Pilosa	31.5	66.0	PB	*Pseudoglyptodon chilensis*	First outgroup is Cingulata; second outgroup is Afrotheria, Boreoeutheria, or Epitheria depending on the root of the tree. All possible 2nd outgroup taxa include at least one representative from the early Paleocene.	*Pseudoglyptodon chilensis* is from the Tinguirirican of Chile and has a minimum age of 31.5 Ma based on radiometric dating (McKenna et al. 2006). The maximum age of the Tinguirirican is no further back than the Eocene-Oligocene boundary (McKenna et al. 2006). Slightly older than *P. chilensis* is an ungual phalanx from the Eocene of Antarctica that Carlini et al. (1990) identified as a megatheroid sloth. Marenssi et al. (1994), citing Carlini et al. (1992), revised the identification of the phalanx to include either ?Tardigrada (sloths) or ?Vermilingua (anteaters). Subsequently, Vizcaíno and Scillato-Yané (1995) described a fragmentary	

						tooth from the Eocene of Antarctica and referred this tooth to Tardigrada, but MacPhee and Reguero (2010) reinterpreted this tooth fragment as Mammalia incertae sedis based on histological evidence. In addition, the ungual phalanx has apparently been lost (MacPhee and Reguero 2010). Given these deficiencies, as well as Rose et al.'s (2005) referral to the Antarctic specimens as controversial forms, we used *P. chilensis* as the oldest pilosan.	
16. Xenarthra	47.8	66.0	PB	*Riostegotherium*		*Riostegotherium* is from the Upper Paleocene (Itaboraian) (Bergqvist et al. 2004); Itaboraian was considered equivalent to the Selandian **(**Benton and Donoghue 2007**)** stage, but Woodburne et al. (2014) suggest an early Eocene age (minimum = 47.8 Ma). First outgroup is Afrotheria, Boreoeutheria, or Epitheria, all of which have early Paleocene representatives.	
17. Proboscidea *(=Loxodonta* to *Elephas)*	6.8			hominid locality in Chad (Vignaud et al. 2002)		Vignaud et al. (2002, report of *Loxodonta* in faunal list); Vignaud et al. (2002) locality was radiometrically dated by Lebatard et al. (2008) to have an age between 6.8 and 7.2 million years. The oldest *Elephas* lineage fossils have a minimum age of 5.332 Mya (Shoshani and Tassy 2005; Tassy 2003).	
18. Hyracoidea *(=Heterohyrax* to *Procavia)*	6.08	11.62	SB	*Dendrohyrax* fossil (Pickford and Hlusko 2007)		Pickford and Hlusko (2007) discussed *Dendrohyrax* fossils from Lukeino (6 Ma) and Lemudong'o (6.1 Ma). They concluded that the Lukeino material (Pickford 2005) "is complete enough to reveal that it belongs to a new species of *Dendrohyrax*". The Lemudong'o fossils are more fragmentary, but there is "little doubt" that Lemudong'o fossils showing the presence of two ridges on the ventral surface of the symphysis belong to *Dendrohyrax* (Pickford and Hlusko 2007). Further, Kuntner et al.'s (2011) phylogenetic analyses suggest that *Procavia* and *Dendrohyrax* are sister taxa to the exclusion of *Heterohyrax* (fig. 2 in Kuntner et al. 2011), which implies that *Procavia* + *Dendrohyrax* and *Heterohyrax* must have been separate from each other before *Dendrohyrax* diverged from *Procavia*. Ambrose et al. (2007) provide radiometric dates.	Stratigraphic bounding with one stage (Springer et al. 2015) instead of two stages (Meredith et al. 2011) for late Miocene, Pliocene, and Pleistocene stages.
19. Sirenia *(=Dugong* to	41.3	59.2	SB	*Eotheroides aegyptiacum*		Minimum based on the inclusion of Lutetian age *Eotheroides aegyptiacum* in crown Sirenia	

Trichechus)						(Vélez-Juarbe et al. 2012; Vélez-Juarbe and Domning 2014, 2015; Springer et al. 2015).	
20. *Elephantulus* to *Rhynchocyon*	15.97	56.0	PB	*Myohyrax*	*Chambius*	*Myohyrax* from early Miocene (McKenna and Bell 1997)	*Chambius* is from Ypresian [maximum = 56.0 Mya, see Tabuce et al. 2008 phylogeny]
21. *Amblysomus* to *Chrysochloris*	1.7	33.9	PB	*Amblysomus julianae*	*Eochrysochloris* (=2nd outgroup)	Avery 2001	Seiffert et al. 2007 (*Eochrysochloris*)
22. Lagomorpha	47.6	61.6	SB/PB	Ypresian tarsals	1st and 2nd outgroups are *Palaeolagus* and *Mimotona* (Meng 2005; Asher et al. 2005), the latter from the late Paleocene (includes Selandian and Thanetian). *Dawsonolagus* (Li et al. 2007) is another stem lagomorph, but has not been included in cladistic analyses.	Ypresian tarsals are from the Vastan mine, India (Rose et al. 2008); Vastan tarsals are crown lagomorphs in phylogenetic analysis (see p. 1205) and are placed as stem leporids. The age of the Vastan mine deposits is Ypresian (minimum = 47.6 Ma)	
23. Chiroptera	47.8	66.0		*Dizzya*		The oldest crown yangochiropterans include *Dizzya* (Philistidae, Vespertilionoidea) from the Ypresian (Eiting and Gunnell 2009). We used the top of the Ypresian as a minimum age for Yangochiroptera.	Phillips (2015) suggested a maximum age for Chiroptera of 58.9 Ma. The oldest bats (earliest Eocene, ~55 Ma) were already highly specialized fliers with fully developed wings (Czaplewski et a. 2008, Simmons et al. 2008). Bats are one of the least common groups of mammals in the fossil record (Czaplewski et a. 2008, Teeling et al. 2005; Meredith et al. 2008b; Eiting and Gunnell 2009), and it is unnecessarily restrictive to enforce a maximum of 58.9 Ma on crown Chiroptera. Furthermore, molecular studies have

							rearranged the evolutionary tree for bats and recovered numerous higher-level clades that were previously unrecognized based on morphological data (Teeling et al. 2000, 2002, 2005). The relationships of several early Eocene fossils (e.g., *Palaeochiropteryx, Archaeonycteris, Hassianycteris*), in turn, lack robust support, and their inclusion or exclusion from crown Chiroptera is sensitive to the enforcement of molecular scaffolds (Springer et al. 2001; Teeling et al. 2005; Simmons et al. 2008). Phylogenetic uncertainties, convergent evolution, and a depauperate fossil record conspire together to limit our understanding of the early evolutionary history of bats and caution against employing a maximum that is younger than the KPg boundary (66 Ma).
24. Emballonuroidea (=Emballonuridae to Nycteridae)	41.3	59.2	SB	*Tachypteron* and *Vespertiliavus*		*Tachypteron* and *Vespertiliavus* are emballonurids from the Lutetian (Eiting and Gunnell 2009). The oldest of these is *Tachypteron franzeni* (Storch et al. 2002). The oldest nycterid is *Chibanycteris* from the Rupelian of Africa (Gunnell and Simmons 2005; Eiting and Gunnell 2009). We used the top of the Lutetian as a minimum age for the split between Emballonuridae and Nycteridae.	
25. Hipposideridae to Rhinolophidae	38.0			*Hipposideros*		*Hipposideros* and *Rhinolophus* are both known from the Eocene of Europe (Gunnell and Simmons 2005). Eiting and Gunnell (2009) indicate that *Hipposideros* first occurs in the Bartonian whereas *Rhinolophus* first occurs in the Priabonian.	
26. Craseonycteridae to	33.9	47.8	PB/PU/ SB	*Saharaderma*	*Necromantis* has possible megadermatid	Eiting and Gunnell 2009	Eiting and Gunnell 2009; Hulva et al. 2007 argues against megadermatid affinities for *Necromantis*

Megadermatidae					affinities and is known from the Lutetian. However, some authors have questioned the affinities of *Necromantis* with megadermatids (Hulva et al. 2007). The association of *Saharaderma* with Megadermatidae is more secure (Eiting and Gunnell 2009).		
27. Molossidae to Vespertilionidae/ Miniopteridae	38.0	56	SB	*Wallia*		Eiting and Gunnell (2009) follow Miller-Butterworth et al. (2007) and regard Miniopteridae as a separate family. However, there are no morphological diagnoses of Vespertilionidae exclusive of Miniopteridae (the latter are traditinally nested inside of Verpertilionidae based on morphology). We therefore calibrated a minimum age for Molossidae to Vespertilionidae/Miniopteridae rather than Vespertilionidae to Miniopteridae. We use the oldest molossid (*Wallia*) (Lim 2009; Eiting and Gunnell 2009). *Stehlinia* is a possible verpertilionid of older age (Lutetian) (Eiting and Gunnell 2009), but some authors (e.g., Simmons and Geisler 1998) place this genus in Nataloidea.	
28. Natalidae to Vespertilionidae/ Miniopteridae/ Molossidae	38.0	56	SB	*Wallia*	*Honrovits*		
29. *Pteronotus* to *Artibeus*	28.1	41.3	SB	Mormoopid, gen. et sp. nov.		Mormoopid, gen. et sp. nov.: early Oligocene =Rupelian): Florida: Gunnell and Simmons 2005; Morgan and Czaplewski 2003; Czaplewski et al. 2008	
30. *Furipterus* to *Noctilio*	5.332	33.9	PB	*Noctilio lacrimaelunaris*	Mormoopid, gen. et sp. nov.	*Noctilio* fossils are known from the Acre vertebrate fauna, which is biocorrelated with Huayquerian (9-6.8 Ma) fossils from other SA localities. We used the end of the late Miocene	PB based on age of mormoopid gen. et sp. nov. (Gunnell and Simmons 2005).

						(5.332 Ma) as a minimum for *Noctilio* (Cozzuol 2006).	
31. Yangochiroptera	47.8	61.6	SB	*Dizzya*		The oldest crown yangochiropterans include *Dizzya* (Philistidae, Vespertilionoidea) from the Ypresian (Eiting and Gunnell 2009). We used the top of the Ypresian as a minimum age for Yangochiroptera.	The oldest possible 1st and 2nd outgroups to Yangochiroptera are extinct lineages (e.g., *Icaronycteris*) and/or yinpterochiropterans, all of which are no older than the Ypresian. We therefore used stratigraphic bracketing for the Yangochiroptera maximum.
32. Caniformia (=Canidae to Arctoidea)	38.0	56	SB	*Hesperocyon gregarious*		*Hesperocyon gregarius* fossils are from the Duchesnean (~ Bartonian) land mammal age in the middle Eocene (Wang and Tedford 1996 in "The Terrestrial Eocene-Oligocene Transition in North America"; *H. gregarius* is a stem canid in Spaulding and Flynn (2009).	
33. Ursidae to other arctoids	28.1	41.3	SB	*Cephalogale*		*Parictis* from the late Eocene of North America may be a stem ursid, but the relationship of this taxon and other amphicynodontids to ursids and other arctoids remain unclear. *Parictis* (putative stem ursid) is known from the Chadronian land mammal age (~ Priabonian) from the late Eocene (Bryant 1993; Krause et al. 2008), but has not been included in phylogenetic analyses. *Parictis* occurs in the early Chadronian (minimum = 35.5 Ma; Hunt 1998a). *Parictis* is sometimes regarded as the oldest ursid (Krause et al. 2008) and is included in the subfamily Amphicynodontinae (or family Amphicynodontidae); other hypotheses (e.g., basal pinniped, McKenna and Bell 1997) have also been proposed. By contrast, *Cephalogale*, which belongs to the ursid subfamily Hemicyoninae, has emerged as a stem ursid in phylogenetic analyses (Finarelli 2008; also see Wang et al. 2005). *Cephalogale* is known from the early Oligocene (Banyue and Zhanxiang 2003). We used the top of the early Oligocene as the minimum for Urside to pinnipeds.	
34. Musteloids to Pinnipeds	23.03	38.0	SB/PB/PU	*Promartes, Enaliarctos*	*Mustelavus*	*Mustelavus priscus* is first known from the latest Eocene (Baskin 1998) and is either a stem musteloid Baskin 1998; Wang et al. 2005; Sato et al. 2009) and the oldest representative of the	

						crown taxon that includes musteloids and pinnipeds, or a deeper lineage within Caniformes (Tomiya 2011). Tomiya's analysis is at odds with molecular studies and recovered *Ursus* inside of crown Musteloidea. Nevertheless, given the uncertainty regarding *Mustelavus* based on Tomiya (2011) we implemented a minimum of 23.03 Ma for the musteloid-pinniped split based on the oldest musteloid (*Promartes*; Baskin 1998; Finarelli 2008) and oldest pinniped (*Enaliarctos*; Uhen 2007), both of which are from the late Oligocene. (2008).	
35. Musteloidea	23.03	38.0	SB/PU	*Promartes*		The oldest crown musteloid may be *M. olivieri* (Wolsan 2005; Sato et al. 2009; age=30.9-32.8 Mya, which is within Rupelian), which is possibly on stem branch to procyonids, mustelids, and ailurids, but this taxon has also been placed outside of crown Musteloidea (Finarelli 2008; Tomiya 2011). The placement of *Promartes* (late Oligocene) as a crown musteloid is more robust (Baskin 1998; Finarelli 2008). The oldest mephitid is *Miomephitis pilgrimi* (17.6-20.3 Mya) from Germany (discussed in Sato et al. 2009).	
36. Phocidae to Otariidae+ Odobenidae	20.43	33.9	SB	*Desmatophoca brachycephala*		*D. brachycephala* is Aquitanian (20.43-23.03 Mya) in age (Demere et al. 2003). The oldest stem pinnipeds are Chattian (e.g., *E. tedfordi*). SB yields an older maximum than PB.	
37. Felidae to Prionodontidae	28.1	41.3	SB	*Proailurus lemanensis*, *Stenogale julieni*		*Proailurus lemanensis* and *Stenogale julieni* are both known from early Oligocene deposits (Quercy, France) (Hunt, 1998b). In the backbone analysis of Wesley-Hunt and Flynn (2005), these taxa emerge as stem felids, although living prionodontids were not included. *Palaeoprionodon* was considered the oldest representative of the *Prionodon* lineage by Hunt (1998b). *Palaeoprionodon* is also known from Quercy, France (early Oligocene = Rupelian). This is generally consistent with Wesley-Hunt and Flynn's (2005) backbone analysis, i.e., *Palaeoprionodon* is sister to felids+stem felids. Holliday (2007, unpublished Ph.D. dissertation) also recovered *Proailurus lemanensis* and *Stenogale julieni* as stem felids in an analysis that	

						included *Prionodon*.	
38. Herpestidae to Eupleridae	15.97	33.9	SB	*Leptoplesictis*		*Leptoplesictis* from Africa is early Miocene in age (Barycka 2007; Veron et al., 2004; Hunt and Tedford 1993) and is the oldest herpestid; the oldest eupleurids are Holocene (Goodman et al. 2004).	
39. Carnivora	38.0	66.0	PU	*Hesperocyon gregarious*	early Paleocene Viverravidae	*Hesperocyon gregarius* is a basal canid in constrained (Wesley-Hunt and Flynn 2005) and unconstrained (Wesley-Hunt and Flynn 2005; Spaulding and Flynn 2009) analyses.	Phylogenetic uncertainty allows for the possibility that viverravids from the early Paleocene are stem feliforms (Flynn 1996; Hunt and Tedford 1993). Benton et al. (2009) also suggested a maximum of 66 Ma for Carnivora.
40. Lorisidae to Galagidae	38.0	56	SB	*Saharagalago misrensis*		*Saharagalago misrensis* is known from the Bartonian (Seiffert et al. 2003) and is assigned to Galagidae; *Karanisia* emerged as a crown lorisid in Seiffert et al.'s (2003) analysis, although these authors also allow for the possibility of stem lorisid or stem lorisiform status for *Karanisia*.	
41. Haplorrhini (=Tarsiidae to Anthropoidea)	38.0	59.2	PU	numerous eosimiids	1st outgroup = omomyoids; 2nd outgroup = strepsirrhines	*Altiatlasius* is know from the late Paleocene and is a stem anthropoid in recent cladistic analyses (Bajpai et al. 2008; Rose et al. 2009), although not in Bloch et al. (2007). *Anthrasimias* (54-55 Mya, Sparnacian, see Bajpai et al. [2008] and Prasad [2009]) is another putative stem anthropoid, although its anthropoid status has been questioned by Rose et al. (2009). *Algeripithecus* is younger (> 45 Mya) and has been referred to Anthropoidea (Seiffert et al. 2005). However, recent discoveries of more complete specimens of *Algeripithecus* suggest that it is not anthropoid (Williams et al. 2010). Instead, it may belong to the Azibiidae, which are argued to be adapiforms, early euprimates, plesiadapiforms (possible stem primates), or even nonprimates (see Williams et al. 2010). As many as 11 species and six genera of Asian eosimiids are known from the middle Eocene of Asia (Williams et al. 2010). The oldest tarsiid is *Tarsius eocaenus* (Beard et al. 1994; Rossie et al. 2006) from the middle Eocene of China (minimum age =38.0 Ma). We used the top of the	Maximum age allows for the possibility that the late Paleocene *Altiatlasius* from Morocco is a stem anthropoid (Williams et al. 2010).

						middle Eocene as a minimum for crown Haplorhini based on the occurrence of numerous eosimiids from the middle Eocene (Williams et al. 2010).	
42. Anthropoidea	28.1	56	PU	*Aegyptopithecus*	*Algeripithecus minutus*	Aegyptopithecus (early Oligocene~Rupelian) is a stem catarrhine in Kay et al.'s (2008, J. Hum. Evol.) cladistic analyses with molecular scaffolds. The oldest stem platyrrhine is Branisella (Kay et al. 2008 cladogram) from the late Oligocene of Bolivia (Salla Beds, Chron 8, age = 25.82-27.02 Mya according to Kay et al. 1998 in JVP)	Seiffert et al. (2005) recovered a polytomy with catarrhines, platyrrhines, Parapithecoidea, Proteopithecidae, and *Algeripithecus minutus*. The age of the latter taxon is Ypresian to basal Lutetian , which established a maximum of 56.0 Mya for the base of Anthropoidea if we allow for phylogenetic uncertainty, i.e., that *Algeripithecus* is either a crown anthropoid or one of the first two outgroups. In contrast, Tabuce et al. (2009) place *Algeripithecus* as a stem strepsirrhine based on more complete material.
43. Catarrhini	20.55	38.0	PB/PU	*Afropithecus turkanensis*	*Catopithecus*	*Afropithecus turkanensis*, previously *Morotopithecus bishopi* (see Harrison and Andrews 2009), is dated at 20.6 +/- 0.5 = 20.55 based on overlying lava (Young and MacLatchy 2004) and is the oldest crown-group catarrhine. It is a stem hominoid (Finarelli and Clyde 2004) or even a crown hominoid (Young and MacLatchy 2004). The oldest cercopithecoid is *Victoriapithecus* (Jensen-Seaman and Hooper-Boyd 2008) at ~19 Mya.	Oligopithecids (including *Catopitheus*) are sometimes regarded as stem catarrhines (e.g., see review of alternate hypotheses in Seiffert and Simons (2001) where *Catopithecus* is sometimes part of second outgroup to crown catarrhines; age of *Catopithecus* is 34.8-33.7 Mya (Chron C13r) based on Seiffert 2006, which is mostly within the Priobonian. We used the base of the Priabonian (38.0 Ma) as the maximum age for the base of Catarrhini.
44. Hominoidea	11.608	28.1	SB	*Sivapithecus*		*Sivapithecus* is the oldest crown hominoid in Finarelli and Clyde's (2004) cladistic and stratocladistic analyses.	
45. Strepsirrhini	38.0	56	SB/PB	*Saharagalago*	Adapiformes	*Saharagalago misrensis* is known from the Bartonian (Seiffert et al. 2003) and is assigned to Galagidae; Karanisia emerged as a crown lorisid in Seiffert et al.'s (2003) analysis, although these authors also allow for the possibility of stem lorisid or stem lorisiform status for *Karanisia*. These are the oldest crown strepsirrhines.	Adapiforms are paraphyletic at the base of crown Strepsirrhini (see Seiffert et al. 2009). The oldest adapiforms are early Eocene.
46. Scandentia (=*Tupaia* to *Ptilocercus*)	38.0	66.0	PB/PU	*Eodendrogale parvum*	Early Paleocene plesiadapiform primates including *Purgatorius*	*Eodendrogale* is known from the middle Eocene Hetaoyuan Formation (Tong 1988) of China. McKenna and Bell (1997) placed this taxon in Tupaiinae, although this taxonomic assignment has not been confirmed with cladistic analyses.	Possible first and second outgroups to Scandentia are Primatomorpha and Glires, both of which include earliest fossils from the early Paleocene (e.g., plesiadapiform primates).

47. Perissodactyla	55.5	61.6	SB	*Hyracotherium*		*Hyracotherium* first appears in Wa-0 at the beginning of the Eocene (Woodburne et al. 2009)	
48. Erinaceomorpha to Soricidae	61.6	83.8	SB	*Adunator*		*Adunator* is the oldest erinaceomorph (Benton et al. 2009) and is known from the Torrejonian (contained within Danian). The miminim age is 61.1 Ma and the maximum is the base of the Campanian (83.6 +/-0.2 = 83.8 Ma) based on SB.	
49. Cetartiodactyla	52.5	66.0	PB/PU	*Himalayacetus*	Mesonychidae	*Himalayacetus* is from shallow benthic zone SB8, which has a minimum age of 52.5 Ma within the Ypresian (Bajpai and Gingerich 1998; Benton et al. 2009; Uhen 2010)	Mesonychids are a possible sister taxon to Cetartiodactyla, or may even be nested with Cetartiodactyla as the sister to Cetacea (see O'Leary and Gatesy 2008).
50. Giraffidae to Antilocapridae	17.8	33.9	SB	*Canthumeryx*		*Canthumeryx* (fossil giraffid; Theodor 2004) and *Paracosoryx* (fossil antilocaprid; Davis 2008) are both known from the early Miocene. *Canthumeryx* is from early Miocene sites in Kenya that have been dated at ~ 17.8 Mya (Drake et al. 1988). *Paracosoryx* is known from the early Hemingfordian (min = 17.5 Mya) (Janis and Manning, 1998, chapter 33).	
51. *Megaptera* to *Eschrichtius*	7.3	23.03	SB	*"Megaptera" miocoena*		*Plesiobalaenoptera quarantellii* is known from Tortonian (11-7 Mya) sediments in Italy (Bisconti 2010). Phylogenetic analyses place this taxon closer to *Megaptera* than to *Eschrichtius*. "Megaptera" miocoena (Kellogg, 1922; Deméré et al., 2005; Steeman et al. 2009) is another crown balaenopterid and is more closely related to *Megaptera novaeangliae* than to *Eschrichtius* (Demere et al. 2005; **2011**). "M." miocoena is known from a diatomite at Lompoc, California. The reported age for this diatomite is 8.2-7.3 Mya based on diatom biostratigraphy (Steeman et al. 2009). We used a minimum of 7.3 Mya for the split between *Megaptera* and *Eschrichtius based on "M." miocoena.*	
52. Bovidae to Moschidae	18	33.9	SB	*Eotragus noyei*		Solounias et al. (1995) described *Eotragus noyei*, which is the oldest and most primitive bovid. The reported age is 18.0-18.3 Mya. The oldest fossils with reasonably certain moschid status are *Micromeryx* from the middle Miocene of Eurasia (Vislobokova and Lavrov 2009). *Dremotherium* from the late Oligocene may belong to Moschidae (Prothero 2008), but the affinities of	The maximum age is based on stratigraphic bounding and is the base of the Rupelian.

						this taxon are less clear (Vislobokova and Lavrov 2009). We used 18.0 as the minimum age for the split between Bovidae and Moschidae based on the age of *Eotragus noyei*.	
53. Suidae to Tayassuidae	15.97	38.0	PB	*Hyotherium*, *Nguruwe*	*Perchoerus*, *Eocenchoerus*	*Hylotherium* and *Nguruwe* are early Miocene in age and were recovered as stem suids by Orliac et al. (2010). *Cynorca* is the oldest stem unequivocal stem tayassuid and is also from the early Miocene. Harris and Li-Ping (2008) regard the late Eocene *Perchoerus* as a tayassuid, but this taxon is a stem suoid in Orliac et al.'s (2010) analysis. Harris and Li-Ping 2008 (in The Evolution of Artiodactyls) regard *Eocenchoerus* as a suid, but this remains to be validated (Orliac et al. 2010). In addition to *Eocenchoerus*, all Oligocene Suidae are Eurasian according to Harris and Li-Ping (2008). However, Orliac et al.'s (2010) cladistic analysis suggests that the earliest unambiguous suids (crown or stem) are early Miocene taxa from Africa (e.g., *Nguwure*) and Eurasia (*Sanitherium, Hyotherium*). Given the uncertainty noted above, we used the top of the early Miocene (15.97 Mya) as the minimum for the tayassuid-suid split.	The oldest possible crown suiforms are from the late Eocene (*Perchoerus*, *Eocenchoerus*) according to Harris and Li-Ping (2008). We therefore used the base of the late Eocene as a maximum for the split between Tayassuidae and Suidae.
54. Whippomorpha	52.5	61.6	SB	*Himalayacetus*		*Himalayacetus* is from shallow benthic zone SB8, which has a minimum age of 52.5 Ma within the Ypresian (Bajpai and Gingerich 1998; Benton et al. 2009; Uhen 2010)	
55. Cetacea	34.0	47.8	SB	*Llanocetus denticrenatus*		*Llanocetus* is known from the La Meseta Formation of Seymour Island, Antarctica, and is latest Eocene in age (Mitchell 1989; Uhen 2010). *Llanocetus* is the oldest crown cetacean and a primitive stem mysticete. The oldest odontocetes are stem odontocetes from the Rupelian (early Oligocene) or more precisely from the late early Oligocene (Uhen 2010), athough there are also older forms that have not been described (Uhen 2010 doesn't provide ages).	
56. Phocoenidae to Monodontidae				*Salumiphocoena stocktoni*			

	12.1	28.1	SB			*Salumiphocoena stocktoni* is from the Valmonte Member of the Monterey Formation in Palos Verdes (Barnes 1976, Syst. Zool). *S. stocktoni* was previously *Loxolithax stocktoni* when it was originally described as a delphinid. Uhen et al. (2008) indicate that the fossil range of *Salumpphocoena stocktoni* begins in the Clarendonian (Cl-1; age = 12.1-12.6 Mya), which establishes a minimum age of 12.1 Mya for the Monodontidae-Phocoenidae split. The oldest monodontid is *Denebola* from the Almejas Formation, Mexico. Uhen et al. (2008) indicate a minimum age of Hh-1 (7.5-9 Mya) for *Denebola*, but also note that fossil *Delphinapterus* are known from the middle Miocene of Asia (end of middle Miocene is 11.608).	
57. Sciuridae to Aplodontiidae	45.7	59.2	SB/PB/ PU	*Spurimus*	*Acritoparamys*	*Spurimus* is the oldest aplodontoid (Flynn and Jacobs 2008a). The oldest fossils are from Ui-1, which has a minimum age of 45.7 Mya in the Uintan (Uintan is within the Lutetian). The oldest sciurid is *Hesperopetes thoringtoni* from the early Chadronian (Emry and Korth 2007) and has a minimum age of 36 Mya. *H. thoringtoni* is older than any of the specimens of *Douglassciurus jefferson*i, which occur higher in the section (Emry and Korth 2007).	*Acritoparamys* is known from the latest Paleocene (Cf1 in Thanetian) (Anderson 2008, ch 18) and is a possible second outgroup to Aplodontoidea + Sciuroidea (Marivaux et al. 2004)
58. Octodontoidea (=*Hoplomys* + *Myocastor* + *Capromys* to Ctenomyidae + Octodontidae)	24.5	38.0	SB/PB	*Sallamys, Xylechimys, Deseadomys*	*Eosallamys*, *Eoespina*, *Eosachacui*, *Eodelphomys*	Recent molecular studies (Galewski et al. 2005; Patterson and Velazco 2008) suggest that *Myocastor*, and possibly *Capromys*, are nested within Echimyidae. The fossil taxa *Sallamys*, *Xylechimys*, and *Deseadomys* (family Echimyidae) are all known from the Deseadean (Vucetich et al. 1999), which is mostly late Oligocene and has a minimum age of 24.5 Ma (Flynn and Swisher 1995; Flynn and Wyss 1998). These fossils establish the minimum age for Echimyidae (inclusive of *Capromys* and *Myocastor*).	*Eosallamys, Eoespina, Eosachacui*, and *Eodelphomys* wee assigned to Echimyidae and are known from the Santa Rosa Local Fauna of Peru (Campbell et al. 2004; Frailey and Campbell 2004). The putative age of this fauna is late Eocene, but this age is based on stage of evolution arguments and remains to be firmly established using more rigorous stratigraphic methods. Hence, we incorporate this information into our maximum age but not our minimum age.
59. Chinchillidae to Octodontidae	24.5	38.0	SB/PB	*Sallamys, Xylechimys, Deseadomys*		See above for oldest fossils belonging to Octodontoidea	As above

60. Ctenomyidae to Octodontidae	9.07	33.9	PB	*Xenodontomys, Palaeoctodon, Chasicomys*	Deseadan Echimyidae (see above) and Deseadan Acaremyidae	*Xenodontomys* and *Palaeoctodon* belong to Ctenomyidae, and *Chasicomys* belongs to Octodontidae (Vucetich et al. 1999). All are Chasicoan in age according to Vucetich et al. (1999), although the oldest *Xenodontomys* fossils are Huayquerian according to Verzi et al. (2004). Zarate et al. (2007) provide a minimum age of 9.07 Mya for mammal bearing deposits from the Chasicoan (early Miocene). Older genera (e.g., Deseadan *Platypittamys*) are sometimes referred to Octodontidae, but phylogenetic relationships of these taxa are uncertain and they may be stem taxa (on branch to Octodontidae+Ctenomyidae) or members of Echimyidae (see Vucetich et al. 1999).	Fossil echimyids, as well as possible stem taxa such as *Platypittamys*, are known from the Deseadean (24.5-29 Mya). The beginning of the Deseadean falls in the early Oligocene (Rupelian), which establishes a maximum of 33.9 +/- 0.1=34.0 Mya.
61. Chinchillidae to Dinomyidae	24.5	38.0	SB	*Eoviscaccia*		*Eoviscaccia* is the oldest chinchillid and is known from the Deseadan (minimum age = 24.5) (Vucetich et al. 1999). Flynn et al. (2003) refer to a chinchillid from the Tinguirrica Fauna (minimum age = 31.0 Mya), but this taxon awaits description. The oldest dinomyids are *Olenopsis* and *Scleromys* from the Santacrucian (16-17.5 Mya; Argot 2004; also see Flynn and Swisher 1995, Flynn et al. 2008 for age of Santacrucian)	
62. Hydrochoeridae to Caviidae	11.8	33.9	PB	*Prodolichotis*	The sister group to Hydrochoeridae + Caviidae is Eocardiidae. The oldest eocardiids are *Chubutomys* and *Asteromys*.	*Prodolichotis* is the oldest caviid and is known from the Laventan (middle Miocene) (Vucetich et al. 1999), which has an age that ranges from 13.5-11.8 Mya (Antoine et al. 2007). The oldest hydrochaerid is *Cardiatherium* (Chasicoan, minimum = 9.07 Mya) (Deschamps et al. 2007)	The sister group to Hydrochoeridae + Caviidae is Eocardiidae. The oldest eocardiids are *Chubutomys* and *Asteromys*, and are Deseadan (Vucetich et al. 1999) in age. The Deseadan extends into the early Oligocene and establishes a maximum age of 33.9 +/-0.1=34.0 Mya.
63. Caviidae +Hydrochaeridae to Dasyproctidae	24.5	38.0	SB/PB	*Asteromys*, *Chubutomys*	*Eopululo wigmorei*, *Eoincamys pascuali*, etc.	*Asteromys* and *Chubatomys* are the oldest eocardiids (Vucetich et al. 1999), and are Deseadean in age (24.5-29 Mya). Eocardiidae is an extinct family that is considered the sister group to Caviidae + Hydrochaeridae (Vucetich et al. 1999).	Agoutidae and Erithizontidae are the first and second outgroups. *Agouti* is known from the late Pleistocene, whereas the oldest erethizontid is *Eopululo wigmorei* from the Santa Rosas Local Fauna of Peru (Frailey and Campbell 2004),

							which is estimated as late Eocene (Mustersan SALMA) based on stage of evolution comparisons for rodents and marsupials (Campbell et al. 2004). There are also dasyproctines (e.g., *Eoincamys pascuali*) from the Santa Rosa Local Fauna (Frailey and Campbell 2004). We used the base of the late Eocene (37.2 +/- 0.1 = 37.3 Mya) as a maximum for this node.
64. Phiomorpha + Caviomorpha	40.94	56	SB/PB	Stem caviomorphs in Antoine et al. (2011) including *Cachiyacuy contamanensis* and other stem caviomorpha	*Glibia*	This calibration was suggested by Phillips (2015) based on fossils that were described by Antoine et al. (2011). We retained minimum and maximum ages suggested by Phillips.	Hartenberger (1998) contends that specimens of the early Eocene *Glibia* are instead the oldest representatives of Phiomyidae. Given this possibility we used the base of the early Eocene as the maximum age for Phiomorpha to Caviomorpha.
65. Geomyoidea	31.4	41.3	SB/PB	*Proheteromys*	*Heliscomys*	*Proheteromys* is the oldest heteromyid (Flynn et al. 2008) and is known from Wh-1 (32.0-31.4 Mya) in the early Oligocene. The oldest geomyids (*Gregorymys, Pleurolicus, Entoptychus*) are from Ar-1 (30.0-28.0 Mya), which bridges the latest Oligocene/early Oligocene (Flynn et al. 2008)	Outgroups to Geomyoidea include Florentiamyidae and Heliscomyidae. The oldest members of the latter family are *Heliscomys* and *Passaliscomys* from the Duchesnean (40.1-36.9 Mya). We used the base of the Bartonian (40.4 +/-0.2 = 40.6 Mya) as a PB maximum. The SB maximum is also 40.6.
66. Castorimorpha (=Castoridae to Geomyoidea)	52.4	61.6	SB	*Mattimys*		*Mattimys* is the oldest castoroid (Flynn and Jacobs 2008b) and is known from Wa-6 (53.5-52.4 Mya) in the early Eocene. *Mattimys* belongs to the family Eutypmyidae, which is regarded as the sister taxon to Castoridae (Flynn and Jacobs 2008b)	
67. Myomorpha (=Muroidea to Dipodidae)	45	59.2	SB	*Pappocricetodon*		Eocene deposits in China with *Pappocricetodon* have been biocorrelated with Bridgerian and early Uintan LMAs of North America (Beard et al. 1994), and suggest an age of ~45 Mya.	SB yields a maximum age of 59.2 Mya for Muroidea + Dipodidae.
68. *Laonestes* to Ctenodactylidae	28.3	47.8	PB/PU	*Fallomus*	*Yuomys*	Assumes a sister-group relationship between diatomyids (including *Laonestes*; Dawson et al. 2006) and ctenodactylids (excluding tataromyines). The oldest diatomyid is *Fallomus* from the early Oligocene (= Rupelian) (Dawson et al. 2006). Tataromyine ctenodactylids Oi.e., *Protataromys*) are know from the Eocene, but	Dawson et al.'s (2006) cladistic analysis resulted in *Tataromys* and *Yuomys* as the first and second outgroups, respectively. The oldest of these is *Yuomys*. Dawson et al. (2006) included a late Eocene species in their cladistic analysis, but *Yuomys* is also known from the middle Eocene

						tataromyines are outside of Ctenodactylinae + Diatomyidae in Dawson et al. (2006; fig. 2).	Xiangchan Formation, China (Martin 2007). The age of the Xiangchan Formation is early middle to middle middle Eocene (Tsubamoto et al. 2004). We used the base of the middle Eocene (i.e., base of Lutetian) as our maximum.
69. Sciuromorpha to Hystricognathi	56	66.0	SB/PB/ PU	*Acritoparamys*	Eurymylids from the early Paleocene (*Heomys*).	*Acritoparamys* is known from the late Paleocene of North America (Anderson 2008, chapter 18). Acritoparamys belongs to Ischyromyidae, which generally included in Sciuromorpha (Simpson 1945; McKenna and Bell 1997; Korth 1994; Janis et al. 2008), even as far up the tree as the stem to Aplodontidae (Janis et al. 2008).	1st outgroup = mouse-related clade. 2nd outgroup = eurymyoids, which are a paraphyletic taxon at the base of Rodentia that are sometimes no more than two outgroups away from crown Rodentia given uncertain resolution (e.g., page 150 in Meng et al. 2003). The oldest eurymylids are early Paleocene (Meng et al. 2005; Janis et al. 2008). Other authors (Asher et al. 2005) have recovered eurymylids as basal Glires. Either way, SB also supports a maximum age of 66.0 Ma.
70. Mammalia	160.7	227	PB/PU	*Ambondro*	*Thomasia*	*Ambondro*, from the Bathonian, is a crown mammal in a variety of analyses (e.g., Luo et al. 2001, Woodburne et al. 2003, reviewed in Benton et al. 2015), although its affinities with monotremes versus therians remain controversial. We followed Benton and used top of the Bathonian is 166.1 +/- 1.2 Ma = 164.9 Ma.	Multitubercuata are generally placed inside of crown Mammalia (e.g., Kielan-Jawoworska et al. 2004). Haramiyids, in turn, may be related to multituberculates (Kielan-Jawoworska et al. 2004; Bi et al. 2014; Krause et al. 2014). The oldest haramiyid is *Thomasia* from the Norian (Lucas and Luo 1993). The oldest mammal fossils are *Adelobasileus* (Lucas and Luo 1993), *Gondwanadon* (Datta 2005), and *Tikitherium* (Datta 2005) from the Carnian, but there is no suggestion that any of these taxa belong to crown Mammalia. Given the uncertainty associated with the placement of Haramiyidae, including *Thomasia*, we employed a maximum of 227 Ma (base of Norian).
71. Galloanserae to Neoaves	66	86.8	SB	*Vegavis iaai*		Clarke et al. (2005); Benton et al. (2009, 2015)	
72. Sauropsida to Synapsida	318	332.9	SB	*Hylonomus lyelli*		*Hylonomus* is from the Joggins Formation of Nova Scotia. The most recent estimates for the age of the Joggins Formation are in the range of 318-319 Ma (Benton et al. 2015, based on Gradstein et al. 2012).	The maximum age is based on the absence of well crown amniotes in well sampled, fossiliferous deposits that occur below the strata with *Hylonomus* (Benton et al. 2015).
73. Archosauria to Lepidosauria	255.9	295.9	Benton et al. (2015)	*Protorasaurus speneri*		*Protorasaurus speneri* is the oldest archosauromorph and has a minimum age estimate of 255.9 Ma (Benton et al. 2009, 2015), which falls within the Wuchiapingian stage of the Permian.	Benton et al. (2015) suggested a maximum age of 295.9 Ma.

74. *Mus* to *Rattus*	10.4 Ma	15.97		*Karnimata darwini*		The Dhok Pathan Formation has an absolute age in the vicinity of 10.4 Ma (Benton et al. 2015) within the Tortonian stage. We used 10.4 Ma as the minimum age for *Rattus* to *Mus* following Benton et al. (2015)	Benton et al. (2015) suggested a maximum constraint of 14.0 Ma based on the oldest record of *Antemurus*, which is found in the Langhian stage. We used the base of the Langhian stage (15.97 Ma) rather than 14.0 Ma for the maximum age of *Mus* to *Rattus*.
75. Rodentia	56.0	66.0	SB	*Acritoparamys, Paramys*		Minimum age recognizes *Acritoparamys* and *Paramys* as crown rodents and agrees with minimum age of Benton et al. (2015).	The earliest crown rodents are at least late Thanetian in age (Benton et al. 2015). Given this age, stratigraphic bounding supports a maximum age of 66.0 Ma. Further, morphological data have not recovered many of the strongly supported rodent clades of molecular studies (Huchon et al. 2002; Churakov et al. 2010; Meredith et al. 2011), suggesting that early rodent evolution was strongly impacted by convergent evolution. The most complete morphological matrix for fossil and extant rodent families (Marivaux et al. 2004) only provides 15% bootstrap support for crown Rodentia. These results allow for the possibility that crown rodents extend as far back as the KPg boundary if not slightly earlier given that rodents are already highly derived when they first appear in the fossil record in the early Paleocene. We follow Benton et al. (2015) and use a maximum age of 66 for crown Rodentia.
76. Paenungulata	59.2	72.3	SB	*Eritherium*		*Eritherium* is a stem proboscidean and is no younger than the late Selandian (Kocsis et al. 2014), which has a minimum age of 59.2 Ma.	
77. Placentalia	62.5	131.5	Benton et al. (2009)			Benton et al. (2009) provides a minimum for Placentalia based on the presence of boreoeutherians in the early Paleocene (e.g. carnivorans, glires, carpolestids)	Benton et al. (2009) provides a soft-maximum calibration for Placentalia based on Liaoning fossils (*Eomaia*, *Sinodelphys*) estimated to be between Barremian (131.5 Ma) and Aptian

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